Incorporation of Surface Wave Effects into a Coastal Ocean Circulation Model

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LONG-TERM GOAL

Our long term goal is to improve coastal ocean prediction and understanding of currents, particle trajectories, water level, waves and tides, and other sea state and hydrographic properties by developing an advanced ocean current and trajectory simulation system. We are particularly interested in how our model products can be used in the coastal region for advanced warning of hazardous ocean conditions so life and property can be protected.

OBJECTIVES

We wish to improve upon the current state of ocean current and trajectory prediction in the coastal zone by developing an **a**dvanced **c**urrent and **t**rajectory **s**imulation **s**ystem (ACTSS) which incorporates the effect of surface waves into a coastal ocean circulation model. At the end of this project, ONR and the scientific community should have a state of the art coastal ocean wave-current model for a variety of coastal applications, and hence an enhanced capability to predict the ocean currents and sea state in the coastal zone.

APPROACH

We adopted a three-pronged approach: 1) numerical modeling, including circulation modeling, wave modeling and coupled current-wave modeling (Lian Xie is leading this effort); 2) data assimilation and model verification, including using remote-sensing data from satellite and radar, in situ high-resolution measurements from the DOE OMP (Department of Energy Ocean Margins Program), and data from other ONR field projects (Leonard Pietrafesa is leading this effort); and 3) theoretical modeling (Lian Xie is leading this effort).

WORK COMPLETED

The following work has been completed since last reporting:

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- The dynamic effect of radiation stress has been incorporated into the wave model (WAM III, cycle 4). This includes improvements made in the CHIEF Program of the WAM model to make the WAM model suitable for simulations under spatially and temporally varying currents;
- The bottom stress formulation in the ocean circulation model (POM) has been improved to include the effect of ocean waves on bottom stress;
- Improvements have been made to the two-way coupler which couples the circulation model and the wave model. With this improvement, model users can now set their own desired spectral resolution in the wave model and spatial resolution in the circulation model.
- Testing of the coupled wave-current model (ACTSS) has been carried out to simulate the currents, surface waves and the interactions between them over the area from Charleston, South Carolina to Chesapeake Bay, Virginia during hurricane Fran of 1996.
- A new technique has been developed to realistically simulate the SAR image from model generated two-dimensional directional wave spectrum. This is an important step toward model verification and data assimilation using SAR data.

RESULTS

It is increasingly evident that surface waves have significant influences on currents in coastal waters both at the surface and near the bottom ((Davis and Lawrence, 1995; Mastenbroek, 1993). To improve our understanding of wave-current interaction under extreme weather conditions, the coupled wave-current modeling system (ACTSS) was used to simulate the response of the coastal ocean to Hurricane Fran of 1996.

Four experiments were carried out: I) surface waves and currents interact only via surface wind stress, II) surface waves and currents interact only via bottom stress, III) surface waves and currents interact via both surface wind stress and bottom stress, and IV) no wave-current interaction. The differences between the results from Experiments I and IV show that surface waves can substantially enhance surface wind stress and increase surface as well as bottom currents and sea surface elevation change. For example, surface currents were enhanced by 0.1-0.8m/s, and bed currents by 0.1-0.4m/s by surface waves depending on the wind distribution and water depth during the passage of Hurricane Fran of 1996 (Fig. 1a). The storm surge maximum near the coast increased by about 0.8 m on the right side of the Hurricane track, while the minimum sea level on the left side of the storm track decreased by as much as 1.1 m. The differences between the results from Experiments I and III indicate that the effect of surface waves on bottom stress caused a decrease in surface and bed currents and the maximum surge level in the coastal water. However, influences of surface wave effects on currents via the bottom stress are relatively small in deeper waters off the shelf break.

As part of the data assimilation project, we have developed a new technique to simulate the SAR image based on the two-dimensional wave spectrum produced by the coupled wave-current model. This technique has been tested for the Hurricane Fran case. We found that this new technique is quite useful for model validation of the coupled wave-current model when SAR images are available. Specifically, our results showed that

1) the propagating direction of surface waves is almost the same in the ocean wave field (Fig. 2a) and in the simulated SAR image (Fig. 2b). In both figures, the waves are propagating roughly in the same direction of the surface wind. However, the width of ocean wave stripes is narrower in the SAR image than in the ocean wave field;

2) in both the wave displacement field and the simulated SAR image, the waves are strongest in the right-front direction of the storm center. In the front and right side of the hurricane track, the surface wave displacement is larger as seen in Fig. 2a. Similarly, in the simulated SAR image, the

ocean wave stripes are clearer. Conversely, in the rear and left side, the surface wave displacement is smaller and in the SAR image, the ocean wave stripes are obscure.

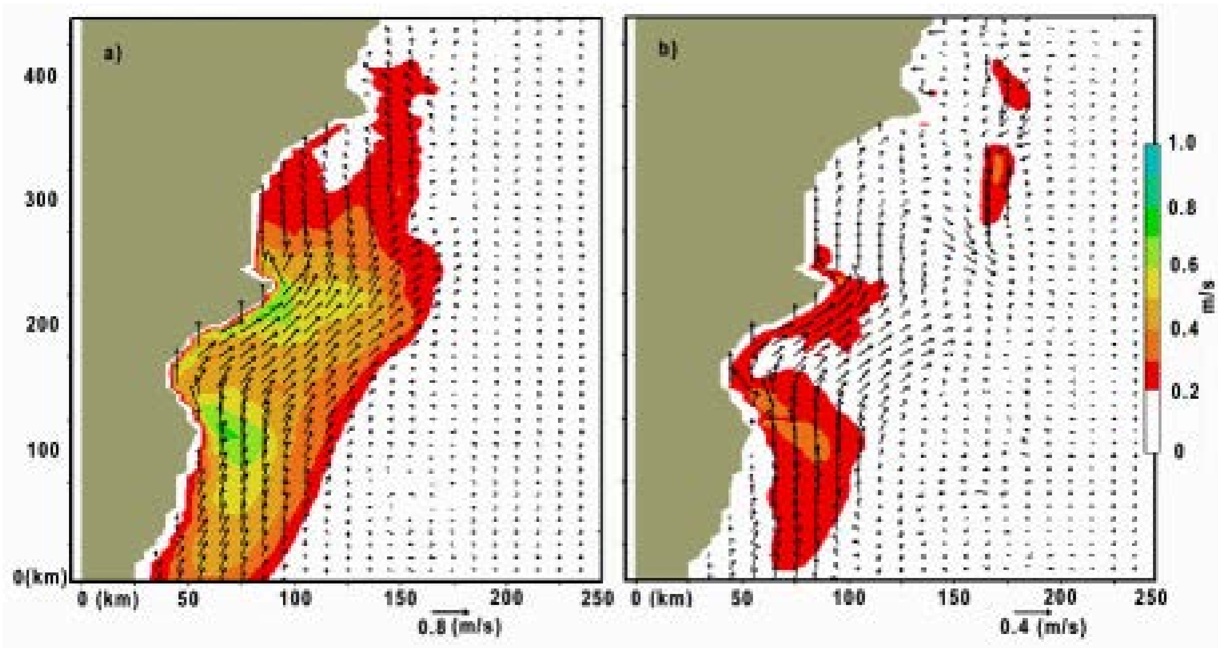

Fig. 1 Differences of surface and bottom current fields between Experiment IV and Experiment I. The color-shade and the length of the arrows both show the magnitude of the differences.

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IMPACT/APPLICATION

The coupled wave-current model we have developed is one of the most advanced wave-current modeling system. We found that surface waves play an important role in coastal ocean response to winds not only through wave-enhanced wind stress, but also through wave-induced bottom stress. This has implications in a number of coastal applications, including but not limited to, accurate storm surge prediction, sediment transport modeling and improved coastal erosion prediction and prevention.

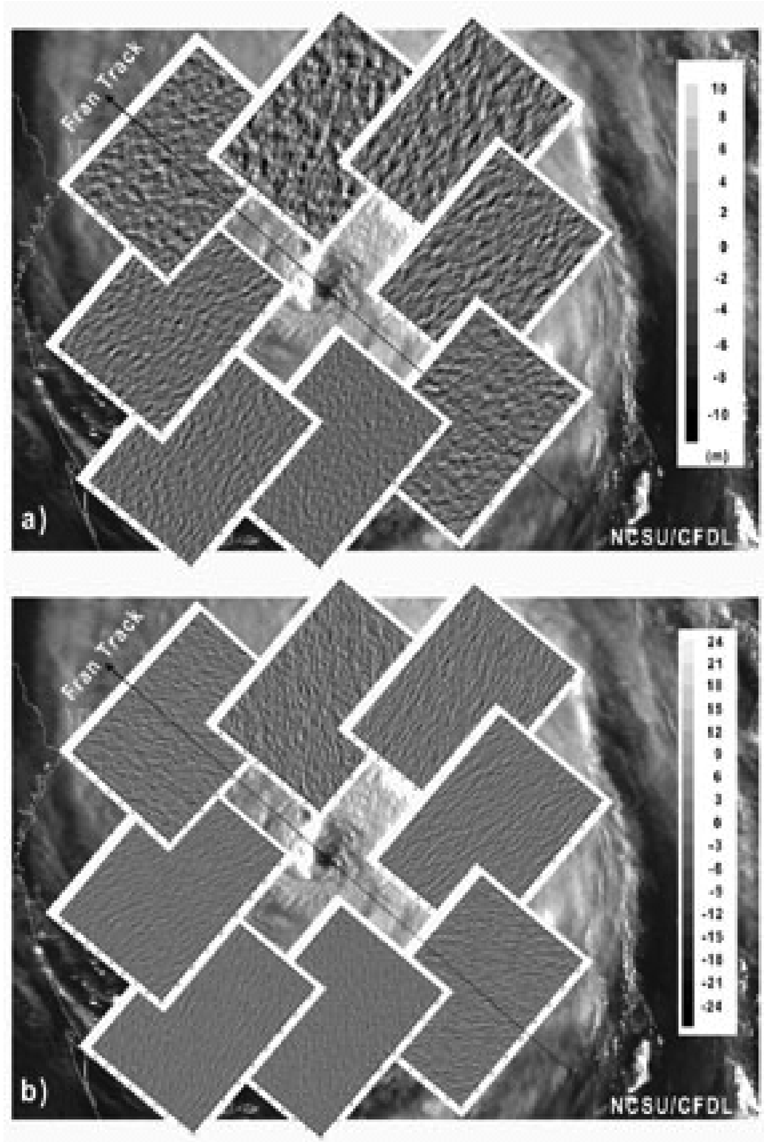

Fig. 2 Surface wave height field and SAR images simulated by ACTSS for the Hurricane Fran case. a) sea surface displacement; b) simulated SAR images.

TRANSITIONS

The preliminary version of our ACTSS modeling system has been used by the National Weather Service to predict the storm surge in North Carolina coastal waters during the 1999 Hurricane season.

RELATED PROJECTS

ACTSS will be the centerpiece of the Coastal Marine Environment Prediction System (CMEPS) (Xie et al., 1999) that is under development at North Carolina State University. Related projects include the following.

1. The coupling of ACTSS to a mesoscale atmospheric model is underway in collaboration with Drs. F. Semazzi and S. Raman (NCSU).

2. Dr. D. Eggleston and Dr. L. Xie are developing a physical-biological coupled model to study the recruitment patterns of blue crabs in North Carolina coastal waters and estuaries.

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